Appendix A. Shuttle Applications of HCFC 141b Blown Foams

This appendix lists SSP parts requiring HCFC 141b blown foams and details major subsystems.

A.1. SSP PARTS REQUIRING HCFC 141b BLOWN FOAMS

The configuration of the Shuttle can change to prevent obsolescence or to support specific mission requirements. Table A.1 lists the types of SSP parts requiring HCFC 141b blown foam insulation.

External Tank	Orbiter	Solid Rocket Booster

♦ Acreage
• LO_2 Tank
  ▪ Barrel
  ▪ Ogive Cover Plate
  ▪ Aft Dome
• Intertank
  ▪ Thrust Panels and High Heat Areas
  ▪ LO_2 and LH_2 Splice Closeouts
  ▪ Intertank/LH_2 and LO_2 Tank Splice
  ▪ Intertank ΔP Measurement
  ▪ Intertank Aerovent
• LH_2 Tank
  ▪ Forward Dome
  ▪ Aft Dome
  ▪ Thrust Strut Fitting (2)
  ▪ Tooling Third Hard Point
  ▪ Aft Longeron Tool Fitting (2)
  ▪ LH_2 Feedline at LH_2 Tank
  ▪ LH_2 Recirculation Line at LH_2 Tank
  ▪ Longeron Electrical Connector
  ▪ Aft Dome Manhole Cover
  ▪ Aft Dome Cover Leak Port
  ▪ LH_2 Tank Bipod Fitting Jack Pad
  ▪ Aft Upper - ET/SRB Fitting Fairing
  ▪ Bipod Strut Support Clevis/Aero Ramp
• Protuberance Airload Ramps
• Ice/Frost Ramps
♦ Penetrations
• LO_2 Feedline
• LH_2 Vent Line
• Aerovents (2)
♦ Structural Attachments
• Bipod Fittings
♦ Interface Structure
• Forward ET/Orbiter Attachment Strut (Bipod)
• LO_2 and LH_2 Feedline to Tank Attachment Closeout
♦ Propulsion Lines
• LO_2 Feedline Flanges
• LH_2 Feedline Leak Ports
• LH_2 Recirculation Line Lead Port
• LH_2 Feedline to Umbilical Plate
	♦ MPS
	• ET insulation LH_2
	• ET insulation LO_2
	• 17" feedline inlet
	• Repress sense line, LH_2
	• LH_2 manifold
	• Feedline outlet, LH_2
	• LH_2 high point bleed
	• LH_2 RTLS dump
	• LH_2 RTLS dump inboard flange
	• Side strut supports, 17" disconnect
	• LH_2 prevalves
	• LH_2 umbilical, Orbiter
	• Purge bracket to LH_2 umbilical
	• LO_2 feeding inlet
	• Engine cutoff sensors
	• LO_2 manifold - forward support struts
	• LO_2 prevalves
	• LO_2 umbilical disconnect
	• LH_2 recirculation pump package
	• LH_2 replenishment valve
	• LH_2 recirculation disconnect valve flange
	• LH_2 prestart cond. manifold
	• GNG. Interface, LH_2 recirculation
	• LH_2 relief sensing line
	• DP transducer
	• LH_2 F&D inboard
	• LH_2 F&D outboard
	• Instrumentation insulation
	• Housing cover
	• Fork housing side
	• Fork housing gauge
	• Fork housing inner side
	• Fork housing base
	• Fork housing base strip
	• Roller housing side
	• Roller housing corner
	• Roller housing edge
	♦ PRSD
		♦ Aft Skirt Insulation Installation
		♦ Aft Skirt TPS Installation Closeout
		♦ Aft Booster Assembly Insulation Closeout
		♦ Frustum Insulation Installation Closeout
		♦ SRB TPS Closeout

External Tank	Orbiter	Solid Rocket Booster
• LH_2 Recirculation Line to Umbilical Plate	• FC 1 LHS installation	
• Helium Inject Box/Cover	• FC 2 & 3 RHS installation	
♦ Nose Cone	• Tank set 1 installation LH	
	• Tank set 2 installation RH	
	• T-0 line & EDO LHS installation	
	• T-0 line & EDO RHS installation	
	• EPS/PRSD complete	
	• Mid-to-aft fuselage installation	
	• T-0 lines aft fuselage installation	
	• Tank set 3 tech order	
	• Tank set 4 tech order	
	• Tank set 5 tech order	
	• Tank set 3 end item	
	• Tank set 4 end item	
	• Tank set 5 end item	
	• EDO pallet end item	
	• LDO pallet end item	
	• EDO pallet PRSD installation	
	• EDO pallet interfacing lines	
	• LDO pallet interfacing lines	

Table A.1 Types of SSP Parts Requiring HCFC 141b Blown Foams

A.2. DETAIL OF MAJOR SSP SUBSYSTEMS REQUIRING HCFC 141b BLOWN FOAM

Two major SSP subsystems require HCFC 141b blown foam insulation: the SSP Main Propulsion (MPS) System and the Power Reactant Storage and Distribution (PRSD) System.

The MPS, assisted by the two Solid Rocket Boosters (SRBs) during the initial phases of the ascent trajectory, provides the velocity increment from liftoff to a predetermined velocity increment prior to orbit insertion. After the two SRBs are expended and jettisoned, the MPS continues to thrust until the predetermined velocity is achieved. The main engine cutoff is then initiated. The External Tank (ET) is jettisoned, and the Orbital Maneuvering System (OMS) is ignited to provide the final velocity increment for orbital insertion. The magnitude of the velocity increment supplied by the OMS depends on payload weight, mission trajectory, and system limitations.

The PRSD subsystem has two major functions. It stores and distributes hydrogen and oxygen to the three fuel cells for electrical power production and distributes oxygen to the Environmental Control and Life Support System (ECLSS) for crew respiration.

A.2.1. SSP Main Propulsion System

The MPS comprises several major subsystems, three of which, the ET, the propellant management/helium subsystems, and the Space Shuttle Main Engines (SSMEs), contain components that require the use of HCFC 141b blown foam.

a.) **External Tank.** The ET contains the liquid hydrogen (LH_2) fuel and liquid oxygen (LO_2) oxidizer and supplies them under pressure to the three main engines in the Orbiter during liftoff and ascent. Each of the main components of the ET has its own TPS requirement based on environments and mission conditions.

1) **LO_2 Tank TPS.** The LO_2 tank upper ogive is covered with foam where the LO_2 tank joins the Intertank. The LO_2 aft dome is also covered with foam. The joining flange where the LO_2 tank meets the Intertank is covered with foam during manufacturing closeout.

2) **Intertank TPS.** Machined foam insulation over the Intertank external surfaces maintains structural temperatures within limits. The smooth contour reduces effective heating and allows application of sufficient foam thickness to meet heating requirements.

The high heat areas of the Intertank that require additional TPS are at interference heat areas between the Orbiter and SRB, and from their attachment structures. The flange joining the Intertank to the LH_2 tank is closed out with foam after the structures are mated.

3) **LH_2 Tank TPS**. The LH_2 tank barrel TPS configuration primarily consists of foam to minimize icing. Exceptions are the domes and areas under protuberances and attachments. The aft dome TPS requirement is primarily driven by propellant quality requirements (temperature and pressure). The aft dome is exposed to high plume (radiant) heating associated with the Orbiter engines and SRBs, as well as convective heat. In addition, the aft dome TPS must preclude LH_2 film boiling. LH_2 thermal stratification during ascent would result in unusable liquid propellant.

This environment requires an initial aft dome TPS thickness sufficient to preserve its function after the dome area has experienced considerable recession in flight. The TPS configuration on the aft dome minimizes stratification and permits all of the liquid propellant to meet interface delivery requirements for engine operation.

Foam insulation is provided on the forward dome to prevent liquification/freezing of the nitrogen used in the Intertank purge. It also stabilizes tank temperature for maintaining LH_2 loading accuracy. The area of the LH_2 tank, near the ET/Orbiter forward and aft interface attachments and the longerons, require added foam thickness to counteract localized, high aerodynamic heating rates.

b.) **TPS Closeouts**. Closeouts are TPS applications conducted after final assembly and checkout to assure that all surfaces are insulated as required. These closeouts are made under controlled temperature, humidity and cleanliness conditions using a portable environmental shelter and additional equipment where required. Large areas are closed out using spray foam; smaller holes require pour foam closeouts.

Closeouts are most critical on areas where the insulation is applied on surfaces subjected to cryogenic temperatures. Unsealed closeouts or voids can result in a loss of insulation due to cryopumping. Cryopumping is a phenomenon wherein the vacuum created by voids in the foam insulation pulls air into the foam interior, close to the substrate. Because the substrate temperature is -423°F (-253°C), the moisture in the air is condensed to liquid (-16°F (-27°C)) or solid/ice (-358°F (-217°C)). This introduction of moisture into the interior of the foam can compromise foam integrity, resulting in loss of TPS material. This phenomenon can reduce insulation efficiency causing a thermal short in the insulation and could cause failure of the insulation during ascent when the solid/liquid air boils.

Most closeouts are made during assembly. A minimal number are made at the launch site after checkout procedures have been completed. Additional TPS closeouts or repairs may be required because of component replacement or the need to refurbish damaged areas.

c.) **17-inch Umbilical**. The ET is attached to the Orbiter at one forward attachment point and two aft points. In the aft attachment area, there are two 17-inch (43-centimeter) disconnect umbilicals that carry fluids, gases, electrical signals, and electrical power between the tank and the Orbiter. These umbilicals are collected into two bundles. Each bundle is permanently connected to the ET, physically supported at one end by a rear attachment strut and terminated in an umbilical plate. Each ET umbilical plate mates with a corresponding Orbiter umbilical plate. The plates help to maintain alignment among the various connecting components. Physical strength at the joint is provided by bolting corresponding umbilical plates together. On the Orbiter side, there are two 17-inch (43-centimeter) disconnect umbilical assemblies, one that allows LH_2 to flow from ET to Orbiter, and another assembly that allows LO_2 to flow from ET to Orbiter. The 17-inch (43-centimeter) disconnect assembly through which LH_2 flows is insulated with HCFC 141b blown foam.

d.) **Orbiter MPS propellant management subsystems.** During engine thrusting, propellants under ET tank pressure flow from the ET to the Orbiter through two umbilicals: one for LH_2 and the other for LO_2. Within the Orbiter, the propellants pass through a system of manifolds, distribution lines, and valves to the main engines. This system also provides a path that allows gases tapped from the three SSMEs to flow back to the ET through two gas umbilicals to maintain pressures in the fuel and oxidizer tanks. During prelaunch, this system is used to control the loading of propellants in the ET. During orbit it controls propellant dump, vacuum inerting, and system repressurization prior to entry.

e.) **Three SSMEs.** The main engines are reusable, high-performance liquid-propellant rocket engines with variable thrust. The propellant fuel is LH_2 and the oxidizer is LO_2. A 12-inch (31-centimeter) flange acts as an interface between SSME and the other components of MPS. This flange is insulated with HCFC 141b blown foam.

A.2.2. Orbiter Power Reactant Storage and Distribution (PRSD)

The primary elements of the PRSD subsystem requiring HCFC 141b foam installation are LO_2 and LH_2 tanks; relief valve/filter package modules; valve modules; feedlines; and fuel cells.

Hydrogen and oxygen are stored in a supercritical condition in double-walled, thermally insulated, spherical tanks with a vacuum annulus between the inner pressure vessel and outer shell of the tank. Each tank has a multi-layer thermal insulation and heaters to add energy to the reactants during depletion for pressure control. The hydrogen and oxygen tanks are grouped in sets consisting of one hydrogen and one oxygen tank. The number of tank sets installed is dependent upon specific mission requirements. If a mission does not need a full complement of tank sets, the extra sets may be removed from the vehicle to reduce weight. The Shuttle vehicle flies with a minimum of 3 tank sets. Four tank sets can store reactants sufficient for a normal 7-8 day mission. For longer duration missions, Atlantis (OV-104) and Endeavor (OV-105) can have a fifth tank set installed under the payload bay liner. They can also have a pallet, referred to as the extended duration Orbiter (EDO) pallet, installed in the payload bay to add four more tank sets.

The tanks are designed to achieve three major functions: (1) storing the reactants at cryogenic temperatures, (2) maintaining the reactants at high pressures, and (3) providing a fluid interface for filling of the tanks and removal of the reactants from the tanks. HCFC 141b blown foam is necessary for proper performance of the feedlines between all of the PRSD elements, including the tank plumbing, manifold plumbing, manifold valves, reactant valves and manifold relief valves.

Cryogenic Storage. The reactants are stored initially at cryogenic temperatures of -420°F (-251°C) for H_2 and -285°F (-176°C) for O_2. The tanks must be capable of maintaining these temperatures for extended periods. Therefore, they are designed to minimize heat leak into the tank. The tanks are double walled. They consist of an inner pressure vessel and an outer shell. The volume between these shells is evacuated on the ground by a vacuum pump, mounted on the side of the tank, to minimize convective heat transfer between the shells. The inner shell is mounted to the outer shell with nonconductive supports to minimize conductive heat transfer. Without these design features, heat leaking into the tank would cause rapid pressure increase of the reactants.

Pressure Maintenance. The pressure of the reactants is kept within specific ranges. At these pressures, the reactants stay in a fluid state (known as the supercritical state) even as the reactant temperatures increase and densities decrease. Reactants are forced out of the tank into the reactant distribution system by the tank pressures. As reactants are removed from a tank, the pressure decreases. The reactants must be maintained in their supercritical fluid state to prevent any of the reactants from becoming gases. The application of HCFC 141b blown foam is necessary for preventing the system from heating up, which in turn causes the reactants to evaporate into gases.

Reactant Distribution. Reactant distribution is responsible for transferring the reactants from the storage tanks to the fuel cells and for supplying O_2 to the ECLSS for crew respiration. The H_2 reactant tanks are connected to an H_2 manifold, and the O_2 tanks are connected to an O_2 manifold. Both manifolds are capable of feeding reactants to all three fuel cells. The O_2 manifold also supplies O_2 through two supplies to ECLSS pressure control systems. The lines that connect the components used for reactant distribution are foamed so that H_2 and O_2 will remain in their liquid state. Without HCFC 141b blown foam, heat will leak into these lines, causing LH_2 and LO_2 to evaporate into gases disrupting the flow of H_2 and O_2.